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(54) **METHOD AND APPARATUS FOR DECODING SECOND ORDER REED-MULLER CODES**

VERFAHREN UND ANORDNUNG ZUR DEKODIERUNG VON ZWEITER ORDNUNG REED-MULLER KODEN

PROCEDE ET APPAREIL POUR LE DECODAGE DE CODES REED-MULLER DU SECOND ORDRE

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Description

BACKGROUND OF THE INVENTION

Technical Field of the Invention

[0001] The present invention relates to the decoding of digital data transmitted over a communications channel and, in particular, to a low complexity maximum likelihood decoder for second order Reed-Muller codes.

Description of Related Art

[0002] There exist many applications where large volumes of digital data must be transmitted and received in a substantially error free manner. In telecommunications systems, in particular, it is imperative that the reception of digital data be accomplished as reliably as is possible. Reliable communication of digital data is difficult, however, because the communications channels (including radio frequency, fiber optic, coaxial cable, and twisted copper wire) utilized for data transmission are plagued by error introducing factors. For example, such errors may be attributable to transient conditions in the channel (like interference, noise or multi-path fading). The influence of such factors results in instances where the digital data is not transmitted properly or cannot be reliably received.

[0003] Considerable attention has been directed toward overcoming this problem and reducing the number of errors incurred when transmitting data. One option involves increasing transmitter power. However, this is typically not practical due to limitations regarding transmitter electronics, regulations on peak power transmission, and the added expense involved in increasing power levels. A preferable alternative option for combating noise on the communications channel is to introduce redundancy in the transmitted message which is used at the receiver to correct introduced errors. Such redundancy is typically implemented through the use of error control coding (channel codes). A preferable alternative option for combating fading on the communications channel is to use an interleaver to reorder the data prior to transmission over the channel. As a result, many communications systems now utilize a combination of error control coding/decoding and interleaving/de-interleaving processes to protect against the effects of interference, noise or multipath fading on the communications channel.

[0004] Because of implementation complexity concerns, the error control decoder typically used comprises a soft decision decoder (and, in particular, an errors and erasures decoder). Such decoders exploit reliability values output from a demodulator in estimating the transmitted codeword. In the absence of fading, and in the presence of Gaussian noise, the optimal soft decision decoder is the maximum likelihood decoder. It is also typically the best decoder in the presence of fading (assuming a good estimate of the fading is available). For a general block code, however, maximum likelihood decoding can be hopelessly complex to implement. Accordingly, a need exists for a less complex maximum likelihood decoding scheme for implementation in connection with soft decision decoding of block codes.

[0005] For the special case of the (24,12) Golay code and the (23,12) extended Golay code, a maximum likelihood decoder having a very low complexity has been devised by Conway and Sloane (see, IEEE Trans. Infor. Theory, vol. 32, pp. 41-50, 1986). The premise behind the Conway-Sloane decoding method is that for a given Golay code, an attempt is made to find a subcode of that given Golay code that is easy to decode. The given Golay code may then be decoded by cycling, to achieve a lower overall complexity, over the subcode and its cosets. For the (24,12) Golay code, for example, it is noted that there is a subcode thereof which is equivalent to a parity check code. Such a parity check code presents a trivial decoding challenge. A more complete explanation of the operation of the Conway-Sloane decoding method may be obtained by referring to the previously mentioned IEEE article, or to U.S. Application for Patent Serial No. 08/768,530, filed December 18, 1996, by Ali S. Khayrallah, et al., the disclosures of which are hereby incorporated by reference.

[0006] The disclosed Conway-Sloane decoding method is limited on its face to application in connection with the Golay and extended Golay codes. Furthermore, an extension of the Conway-Sloane decoding method has been proposed by the above-referenced U.S. Application for Patent in decoding various shortened (19,7), (18,7) and (18,6) Golay codes. In spite of these advances relating to more efficient decoding of Golay codes, a need still exists for less complex maximum likelihood decoding schemes specifically addressing other types of codes. In particular, there is a need for such a scheme in connection with the decoding of second order Reed-Muller codes.

[0007] It is noted that Ran, et al., have disclosed certain algorithms and processes for maximum likelihood soft decoding of second order Reed-Muller codes and the extended Golay code. By using appropriately selected cosets of of a subcode of the code under consideration, more efficient decoding algorithms may be applied.

SUMMARY OF THE INVENTION

[0008] To address the foregoing and other problems, the decoder of the present invention processes a received

vector of second order Reed-Muller (or Kerdock) encoded information by cycling over all of the cosets of a subcode of the second order Reed-Muller (or Kerdock) code, and performing a Fast Hadamard Transformation on the received vector with each cycle to obtain an intermediate codeword guess with respect to each examined coset. Once cycling through the cosets is completed, a final codeword guess (comprising the best one of the intermediate codeword guesses) of the received vector is obtained. The originally encoded information bits are then recovered from this final codeword guess.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] A more complete understanding of the method and apparatus of the present invention may be acquired by reference to the following Detailed Description when taken in conjunction with the accompanying Drawings wherein:

FIGURE 1 is a functional block diagram of a block coding system of the present invention; and
FIGURE 2 is a flow diagram illustrating the decoding process implemented by the channel decoder of FIGURE 1 for second order Reed-Muller codes.

DETAILED DESCRIPTION OF THE DRAWINGS

[0010] Reference is now made to FIGURE 1, wherein there is shown a block diagram of a block coding system 100 of the present invention. The system 100 includes a transmit side 102 and a receive side 104. On the transmit side 102, the system 100 includes an (n,k;d) linear block channel encoder 106 wherein a block of "k" information bits received from an information source encoder 108 is encoded to output a codeword of "n" bits in length (wherein n>k). The channel encoder 106 preferably implements an error control code. An example of the information source encoder 108 is a vocoder or data compressor. The code words output from the channel encoder 106 are then rearranged by an interleaver 110. A modulator 112 then maps the rearranged code words into waveforms suited for transmission over a communications channel 114. An example of such a modulator 112 is any known modulator having an M-ary signal constellation (like quadrature amplitude modulation (QAM) or phase shift keying (PSK)). The communications channel 114 is typically a wireless medium which suffers from many error and distortion introducing problems including fading, interference and noise.

[0011] On the receive side 104, the system 100 includes an appropriate demodulator 116 that demodulates the communications channel 114 transmitted communication and outputs estimates of the rearranged code words. The demodulator 116 further outputs soft information comprising a reliability value for each estimated code word. The reliability values are indicative of the level of confidence expressed by the demodulator 116 in its estimate of a particular received and demodulated code word. Demodulators 116 producing code word estimates and reliability values are well known in the art, and thus will not be further described. Examples of such demodulators 116 include: a maximum aposterior probability (MAP) demodulator, or a soft output Viterbi algorithm (SOVA) demodulator/decoder. The estimated code words and corresponding soft information are then reordered (i.e., de-rearranged) by a de-interleaver 118. An (n,k;d) linear block channel decoder 120 then processes the reordered estimated code words and corresponding soft information to generate estimates of the information bits for output to an information source decoder 122. The channel decoder 120 preferably comprises a maximum likelihood decoder for the selected error control code which utilizes soft decision decoding.

[0012] In accordance with the present invention, the channel encoder 106 implements a second order Reed-Muller code. An (n,k;d) Reed-Muller code is determined by two parameters: m and r≤m, wherein:

$$\begin{aligned} n &= 2^m \\ k &= 1 + \binom{m}{1} + \cdots + \binom{m}{r} \\ d &= 2^{m-r} \end{aligned}$$

For r=1, a first order Reed-Muller code is presented, some examples of which include the (8,4;4) Reed-Muller code, the (16,5;8) Reed-Muller code and the (32,6;16) Reed-Muller code. For r=2, on the other hand, a second order Reed-Muller code is presented, some examples of which include the (16,11;4) Reed-Muller code, and the (32,16;8) Reed-Muller code. The channel encoder 106 of FIGURE 1 preferably, but not exclusively, implements as its second order code the (32,16;8) Reed-Muller code. As an alternative, the channel encoder 106 may implement a class of nonlinear codes (commonly referred to as Kerdock codes) sandwiched between first and second order Reed-Muller codes.

[0013] Although the present invention focuses on the decoding of second order Reed-Muller (or Kerdock) codes, a more complete understanding of the present invention may be obtained from further understanding a well known less

complex procedure used for maximum likelihood decoding of first order Reed-Muller codes. A Sylvester-type Hadamard matrix may be constructed as follows:

$$H_0=[1] \tag{1}$$

$$H_m=\begin{bmatrix} H_{m-1} & H_{m-1} \\ H_{m-1} & -H_{m-1} \end{bmatrix} \tag{2}$$

The columns of $H^{(k)}$ are the code words of the Hadamard code in a specific order. One way to construct a first order (2^m, m+1, 2^{m-1}) Reed-Muller code is to take as code words the rows of H_m (referred to as $\mathbf{y}_0, \ldots, \mathbf{y}_{2^m-1}$), and their 2^m additive inverses (referred to as $\mathbf{y}_{2^m}, \ldots, \mathbf{y}_{2^{m+1}-1}$). Note here that code word $\mathbf{y}_i$ corresponds to the information bits making up the natural binary representation of i. If one of these code words is generated and transmitted, it is received as a receive vector $\mathbf{r} = (\mathbf{r}_0, \ldots, \mathbf{r}_{n-1})$. The maximum likelihood decoding of the received vector reduces to the following process:

- compute the fast Hadamard Transform (HT)

$$\hat{r} = (\hat{r}_0, \ldots, \hat{r}_{n-1}) = r\,H_m,$$

- find I = arg max $|\hat{r}|$,
- if $\hat{r}_I > 0$, then guess y_I was the sent code word,
- otherwise, guess y_{I+2^m} was sent the sent code word,
- recover the information bits from I and J of the guessed code word.

Maximum likelihood decoding of a first order Reed-Muller code using the above less complex process requires m x (2^m - 1) additions and 2^m - 1 comparisons. This is much more efficient than the "brute force" (i.e., complex) maximum likelihood decoding process which requires 2^{m+1} x (2^m - 1) additions and 2^m - 1 comparisons.

[0014] Reference is now once again made to the reduced complexity maximum likelihood decoder for Golay codes devised by Conway and Sloane (see, IEEE Trans. Infor. Theory, vol. 32, pp. 41-50, 1986). It will be remembered that in accordance with the disclosed Conway-Sloane procedure an attempt is made to find a subcode of a given Golay code that is less complex to decode. The given Golay code may then be maximum likelihood decoded by cycling, to achieve a lower overall complexity, over the found subcode and its cosets. The foregoing Conway-Sloane decoding method presents a general premise that for any given highly complex block code, an attempt should be made to find a subcode of that given block code that is less complex to decode. The given complex block code may then be maximum likelihood decoded with reduced complexity by cycling over the subcode and its cosets. Extending this general premise to Reed-Muller codes, and in particular to the second order Reed-Muller code used by the channel encoder 106, it is proposed that reduced maximum likelihood decoding complexity may be obtained by cycling over a found subcode (and its cosets) of the second order Reed-Muller code. The first order Reed-Muller code (discussed above) comprises just such a suitable subcode which, like the parity check for the Golay codes analyzed by Conway and Sloane, and in accordance with the previous decoding description, has a known less complex maximum likelihood decoding solution utilizing a fast Hadamard Transform (as discussed above).

[0015] Consideration is now specifically given to a second order (n,k;d) Reed-Muller code C wherein:

$$n = 2^m$$

$$k = 1 + m + \frac{m(m-1)}{2}$$

$$d = 2^{m-r}$$

This second order Reed-Muller code C contains a first order ($n,k^{(1)};d^1$) Reed-Muller subcode $C^{(1)}$ wherein:

$$n = 2^m$$

$$k^{(1)} = 1 + m$$

$$d^1 = 2^{m-r}$$

The code words of the second order Reed-Muller code C may be generated as the union of the code words of the first order Reed-Muller subcode $C^{(1)}$ and its cosets in C. To produce the cosets, consideration must be given to another (n, $k^{(2)}$;d^2) Reed-Muller subcode $C^{(2)}$ wherein:

$$n = 2^m$$

$$k^{(2)} = k - k^{(1)} = \frac{m(m-1)}{2}$$

$$d^2 = 2^{m-r}$$

The code words of the Reed-Muller subcode $C^{(2)}$ are denoted $\mathbf{z}_0, \cdots, \mathbf{z}_{2k^{(2)}-1}$, with $\mathbf{z}_0$ being the all zero code word in binary representation. The cosets of the Reed-Muller subcode $C^{(1)}$ are then defined as follows:

- for each $\mathbf{z}_1$ in the subcode $C^{(2)}$,

$$C^{(1,j)} = \{y_i + z_j, \text{ all } y_i \in C^{(1)}\}$$

These cosets $C^{(1,j)}$ are disjoint, and their union is equal to the second order Reed-Muller code C.

[0016] With the subcode comprising the first order Reed-Muller subcode $C^{(1)}$ and its cosets $C^{(1,j)}$, the general premise underlying the Conway-Sloane decoding method may be extended to decoding the second order Reed-Muller code C. If a code word in the second order Reed-Muller code C is generated and transmitted, it is received as a receive vector $\mathbf{r}=(r_0,\ldots,r_{n-1})$. Instead of comparing $\mathbf{r}$ directly to a coset $C^{(1,j)}$, a sign change is first performed to obtain $\mathbf{r}'$:

$$r' = r * \underline{z}_j \qquad (3)$$

wherein: the multiplication (*) is performed on an element by element basis; and $\underline{\mathbf{z}}_j$ comprises $\mathbf{z}_j$ in bipolar form (where 0 in binary becomes +1, and 1 in binary becomes -1).
It is noted here that a code word $\mathbf{y}_i + \mathbf{z}_j$ in C, with component $\mathbf{y}_1$ in $C^{(1)}$ and $\mathbf{z}$ in $C^{(2)}$, corresponds to k information bits where the first $k^{(1)}$ bits comprise the natural binary representation of i, and the remaining $k^{(2)}$ bits comprise the natural binary representation of j. The maximum likelihood decoding of the received vector then reduces to the following process:

- $l=0$, $\rho=0$
- for $j=0 : 2^{k(2)} - 1$
  - change signs using Equation (3),
  - compute the fast Hadamard Transform

$$\hat{r} = (\hat{r}_0, \ldots, \hat{r}_{n\,1}) = r' H_m,$$

  - find $l' = \arg\max |\hat{r}|$,

- if $|\hat{r}_{l'}| > \rho$, then

  - $\rho = |\hat{r}_{l'}|$,
  - if $r_l > 0$ then $l=l'$, otherwise $l=l'+2^m$,
  - $J=j$,

- end

- end
- guess $\mathbf{y}_l + \mathbf{z}_J$ was the sent code word,
- recover the information bits from I and J where the first $k^{(1)}$ bits comprise the natural binary representation of I, and the remaining $k^{(2)}$ bits comprise the natural binary representation of J.

Maximum likelihood decoding of a second order Reed-Muller code using the above less complex process requires $2^{k(2)} \times m \times 2^m$ additions and $2^k - 1$ comparisons. This is much more efficient than the "brute force" (i.e., complex) maximum likelihood decoding process which requires $2^k \times (2^m - 1)$ additions and $2^k - 1$ comparisons.

[0017] The Hadamard matrix H_m may be rewritten as a product of m matrices:

$$H_m = E_1 \times \cdots \times E_m$$

where E_i is a ($2^m \times 2^m$) matrix with two nonzero (i.e., +1 or -1) entries per column. In addition, for m'<m:

$$F_{m'} = E_1 \times \cdots \times E_{m'}$$

is a block diagonal matrix where the blocks are equal to $H_{m'}$. As discussed above, the rase Hadamard Transform (HT) is taken over the cosets for the $2^{k(2)}$ versions of $\mathbf{r}'$ given by Equation (3). An examination of the code words $\mathbf{z}_j$ of the Reed-Muller subcode $C^{(2)}$ reveals that parts of the taken fast Hadamard Transform are needlessly recomputed during the recycling operation. Consequently, intermediate values of the Hadamard Transform are stored and used as needed to achieve significant savings in computations.

[0018] Reference is now made to FIGURE 2 wherein there is shown a flow diagram illustrating the decoding process implemented by the channel decoder 120 of FIGURE 1 for second order Reed-Muller codes. In step 200, the vector of the coded information is received. The process then precomputes and stores intermediate fast Hadamard Transform values in step 202. The decoder is then initialized in step 204 with j=-1. A determination is then made in step 206 as to whether all cosets have been exhausted (i.e., whether $j = 2^{k2} - 1$). If not, j is incremented in step 208. Then, in step 210, for the current value of j, an intermediate codeword guess is obtained over the coset $C^{(1,j)}$ of the subcode $C^{(1)}$. The precomputed intermediate Fast Hadamard Transform values from step 202 are retrieved and further processed to complete the Hadamard Transform to produce the intermediate codeword guess. The process then returns to decision step 206. Once the process has cycled over all the cosets $C^{(1,j)}$ of the subcode $C^{(1)}$, and found through completion of the Fast Hadamard Transform process an intermediate codeword guess at each cycle, the final codeword guess (comprising the best of the intermediate codeword guesses) is obtained therefrom in step 212. Decoding of the final guess is then performed in step 214.

[0019] A more complete understanding of the present invention may be obtained now by examining the reduced complexity maximum likelihood decoding process for a specific second order Reed-Muller code. Take, for example, the second order (32,16;8) Reed-Muller code C (m=4, r=2). One subcode C^1 thereof comprises the first order (32,6;16) Reed-Muller code. Also, subcode $C^{(2)}$ comprises a (32,10;8) subcode of the second order Reed-Muller code. For the subcode $C^{(2)}$, its code words are parsed into four blocks s, each of length eight. For s=1,2,3,4, let A_s denote the set of distinct blocks of length eight taken by block s of code words in the subcode $C^{(2)}$. Also, let α_s denote the size of A_j Then, α_1=8, α_2=64, α_3=64, and α_4=128.

[0020] If a code word in the second order Reed-Muller code C is generated and transmitted, it is received as a receive vector $\mathbf{r} = (r_0, \ldots, r_{n-1})$. The vector $\mathbf{r}$ is then parsed into four blocks $\mathbf{r}_1,\mathbf{r}_2,\mathbf{r}_3,\mathbf{r}_4$ of length eight each. As an alternative, it is noted that parsing into eight blocks of length four each, or perhaps something in between, is also equally available. The same is true for two blocks of length sixteen each, or sixteen blocks of length two each. The choice of four blocks of length eight each yields the best compromise between computation and storage. For each $\mathbf{r}_s$, α_s Hadamard Transforms are computed and stored using the eight-by-eight matrix H_3. Then, for each code word $\mathbf{z}_j$, the appropriate values of the α_s Hadamard Transforms are retrieved from memory, and used to complete the Hadamard Transform for multiplying the retrieved values by $E_4 \times E_5$. In this regard, it noted that F_3 is a 32x32 block diagonal matrix where each

block is equal to H_3, and that $H_5=F_3xE_4x\ E_5$. Consequently, multiplying the intermediate values by E_4 x E_5 completes the Hadamard Transform of length thirty-two.

[0021] Some simplifications are available. Looking first at the sets A_s, the additive inverse of each pattern in A_4 is also in A_4. Accordingly, the sixty-four included additive inverses may be deleted since their Hadamard Transforms need not be computed, giving A'_s with $\alpha'_4=64$. Then, $A'_s=$ As, and $\alpha'_s=\alpha_s$ for s=1,2,3. It is next recognized that in some instances the pattern $\underline{u}$ in A'_s coincides with a row of H_3 or its additive inverse (except for the first row). Accordingly:

$$(r_s * \underline{u})\ H_3 = r_s\ H_3\ P \tag{4}$$

wherein: P is simply a permutation.

Hence, there is no need to compute and store the Hadamard Transforms for such a pattern $\underline{u}$ in A'_s, giving A''_s with $\alpha''_s=57$ for s=2,3,4. Then, $A''_s= A'_s$, and $\alpha''_s= \alpha'_s$ for s=1. In summary, we then obtain new sets A''_s with respective sizes of $\alpha''_1=8$, $\alpha''_2=57$, $\alpha''_3=57$, and $\alpha''_4=57$, and $\sum\alpha_s = 179$.

[0022] A full description of the operation of the channel decoder 120 may now be given. Let, $\underline{u}_{s,1}$ denote pattern number 1 in A''_s. Then, let:

$$\hat{r}_{s,l} = (r_s * \underline{u}s,l)\ H_3 \tag{5}$$

For each code word z_j of the Reed-Muller subcode $C^{(2)}$, let 1(j,s) denote the appropriate index in A''_s pointing to the location of block s in z_j, and let P(j,s) denote the permutation matrix to account, if needed, for Equation (4). The maximum likelihood decoding of the received vector by the channel decoder 120 for the second order (32,16;8) Reed-Muller code is then implemented by the following process:

- compute $\hat{r}_{s,l}$, s=1,2,3,4, l=1, ..., α''_s, according to Equation (5),
- 1=0, ρ=0
- for j=0 : $2^{k(2)}$ - 1
  - access stored values of $\hat{r}_{s,1}$, s=1,2,3,4,
  - permute values using P(j,s), s=1,2,3,4, if needed,
    - multiply by E_4 x E_5 to complete the Hadamard Transform of $\hat{r}$,
  - find l' = arg max $|\hat{r}|$,
  - if $|\hat{r}_{l'}| > \rho$, then
    - $\rho = |\hat{r}_{l'}|$,
    - if $\hat{r}_l > 0$ then l=l', otherwise l=l'+2^m,
    - J=j,
  - end
- end
- guess $\mathbf{y_l} + \mathbf{z_J}$ was the sent code word,
- recover the information bits from I and J.

Each H_3 requires $3x2^3$=24 additions, for a total of 24x179=4,296 additions. Each E_4 x E_5 requires 2x32 additions, and must be repeated 2^{10} times, for a total of 65,536 additions. Overall, this gives 69,832 additions. To store the intermediate Hadamard Transform values, 179x8=1,432 memory units must be provided. Finally, there is a need for 2^{16}-1 comparisons. This is much more efficient than the "brute force" (i.e., complex) maximum likelihood decoding process which requires 2^{16}x31=2,031,616 additions, or a ratio of twenty-nine times more additions than the reduced complexity implementation of the present invention.

[0023] Utilizing the teachings herein, as well as the teachings of commonly assigned, co-pending U.S. Application for Patent Serial No. 08/768,530, filed December 18, 1996, by Ali S. Khayrallah, et al., the reduced complexity maximum likelihood decoding process of the present invention may be extended to shortened forms of second order Reed-Muller codes such as the second order (30,14;8) shortened Reed-Muller code, or the second order (28,14;6) shortened Reed-

Muller code. Thus, to extend the efficient decoding process described above for use in connection with the decoding of shortened Reed-Muller codes, the generator matrix for the Reed-Muller code is modified to produce a modified generator matrix that is specific for and tailored to the decoding of each shortened code. The modified generator matrix is then efficiently implemented in the efficient decoding process to identify the best codeword for conversion to its corresponding information bits for output. In particular, the modified generator matrix comprises the Reed-Muller code generator matrix with specially chosen rows and columns deleted.

[0024] The channel decoder 120 is preferably implemented as a specialized digital signal processor (DSP) or in an application specific integrated circuit (ASIC). It will, of course, be understood that the channel decoder 120 may alternatively be implemented with the de-interleaver 118 and source decoder 122 in combination or using discrete components and perhaps distributed processing. In either case, the de-interleaver 118, channel decoder 120 and source decoder 122 each perform and implement the functional operations previously described.

Claims

1. A method for maximum likelihood decoding of a received vector comprising encoded information bits, comprising the steps of:

   pre-computing (202) and saving a plurality of intermediate values for a Hadamard Transformation of the received vector;

   cycling (206) over cosets of a subcode of a second order Reed-Muller code used to encode the information bits,

   performing (210) the Hadamard Transformation on the received vector compared to each coset to obtain an intermediate codeword guess for each cycle; and

   recovering (214), following cycling through each of the cosets, the originally encoded information bits from a final codeword guess (212) comprising a best one of the intermediate codeword guesses.

2. The method of claim 1, ***wherein*** said subcode comprises a first order Reed-Muller code.

3. The method as in claim 1, ***wherein*** the step of performing a Hadamard Transformation on the received vector further comprises the steps of:

   recalling necessary ones of the precomputed intermediate values at each cycle; and

   completing the Hadamard Transformation of the received vector using the recalled precomputed intermediate values to obtain the intermediate codeword guess with respect to each coset.

4. The method as in claim 1, ***wherein*** the Hadamard Transformation comprises a Fast Hadamard Transformation.

5. The method as in claim 1, ***wherein*** the second order Reed-Muller code comprises a shortened form of the second order Reed-Muller code.

6. The method as in claim 1, ***wherein*** the second order Reed-Muller code comprises a Kerdock code.

7. A method for maximum likelihood decoding of a received vector comprising encoded information bits, comprising the steps of:

   precomputing (202) and saving a plurality of intermediate values for a Hadamard Transformation of the received vector;

   cycling (206) over cosets of a subcode of a Kerdock code used to encode the information bits, the subcode comprising a first order Reed-Muller code;

   performing (210) a Hadamard Transformation on the received vector compared to each coset to obtain an intermediate codeword guess for each cycle; and

recovering (214), following cycling through each of the cosets, the originally encoded information bits from a final codeword guess (212) comprising a best one of the intermediate codeword guesses.

8. The method as in claim 7, ***wherein*** the Hadamard Transformation comprises a Fast Hadamard Transformation.

9. The method as in claim 7, ***wherein*** the step of performing a Hadamard Transformation on the received vector further comprises the steps of:

recalling necessary ones of the precomputed intermediate values at each cycle; and

completing the Hadamard Transformation of the received vector using the recalled precomputed intermediate values to obtain the intermediate codeword guess with respect to each coset.

Patentansprüche

1. Verfahren zum Maximum-Likelihood-Dekodieren eines empfangenen Vektors, der kodierte Informationsbits umfasst, umfassend die Schritte:

Vorausberechnen (202) und Speichern einer Vielzahl von Zwischenwerten für eine Hadamard-Transformation des empfangenen Vektors;

zyklisches Laufen (206) über Nebenklassen eines Unterkodes eines Reed-Muller-Kodes zweiter Ordnung, der zur Kodierung der Informationsbits verwendet wurde,

Durchführen (210) der Hadamard-Transformation bezüglich des empfangenen Vektors verglichen mit jeder Nebenklasse, um eine Zwischen-Kodewortschätzung für jeden Zyklus zu erhalten; und

Wiedergewinnung (214), nach dem zyklischen Laufen durch jede der Nebenklassen, der ursprünglich kodierten Informationsbits aus einer abschließenden Kodewort-Abschätzung (212), welche eine beste der Zwischen-Kodewortabschätzungen umfasst.

2. Verfahren nach Anspruch 1, wobei der Unterkode einen Reed-Muller-Kode erster Ordnung umfasst.

3. Verfahren nach Anspruch 1, wobei der Schritt der Durchführung einer Hadamard-Tansformation bezüglich des empfangenen Vektors ferner die Schritte umfasst:

Zurückrufen von notwendigen vorausberechneten Zwischenwerten zu jedem Zyklus; und
Vollenden der Hadamard-Transformation des empfangenen Vektors unter Verwendung der zurückgerufenen vorausberechneten Zwischenwerte, um die Zwischen-Kodewortabschätzung bezüglich jeder Nebenklasse zu erhalten.

4. Verfahren nach Anspruch 1, wobei die Hadamard-Transformation eine schnelle Hadamard-Transformation umfasst.

5. Verfahren nach Anspruch 1, wobei der Reed-Muller-Kode zweiter Ordnung eine verkürzte Form des Reed-Muller-Kodes zweiter Ordnung umfasst.

6. Verfahren nach Anspruch 1, wobei der Reed-Muller-Kode zweiter Ordnung einen Kerdock-Kode umfasst.

7. Verfahren zur Maximum-Likelihood-Dekodierung eines empfangenen Vektors, der kodierte Informationsbits umfasst, umfassend die Schritte:

Vorausberechnen (202) und Speichern einer Vielzahl von Zwischenwerten für eine Hadamard-Transformation des empfangenen Vektors;

zyklisches Laufen (206) über Nebenklassen eines Unterkodes eines Kerdock-Kodes, der zur Kodierung der Informationsbits verwendet wurde, wobei der Unterkode einen Reed-Muller-Kode erster Ordnung umfasst;

Durchführen (210) einer Hadamard-Transformation bezüglich des empfangenen Vektors verglichen mit jeder Unterklasse, um eine Zwischen-Kodewortabschätzung für jeden Zyklus zu erhalten; und

Wiedergewinnung (214), nach dem zyklischen Laufen durch jede der Nebenklassen, der ursprünglich kodierten Informationsbits aus einer abschließenden Kodewort-Abschätzung (212), welche eine beste der Zwischen-Kodewortabschätzungen umfasst.

8. Verfahren nach Anspruch 7, wobei die Hadamard-Transformation eine schnelle Hadamard-Transformation umfasst.

9. Verfahren nach Anspruch 7, wobei der Schritt zur Durchführung einer Hadamard-Transformation bezüglich des empfangenen Vektors weiterhin die Schritte umfasst:

Zurückrufen von notwendigen vorausberechneten Zwischenwerten zu jedem Zyklus; und

Vollenden der Hadamard-Transformation bezüglich des empfangenen Vektors unter Verwendung der zurückgerufenen vorausberechneten Zwischenwerte, um die Zwischen-Kodewortabschätzung bezüglich jeder Unterklasse zu erhalten.

Revendications

1. Procédé pour le décodage avec maximum de vraisemblance d'un vecteur reçu comprenant des bits d'information codés, comprenant les étapes de :

pré-calcul (202) et sauvegarde d'une pluralité de valeurs intermédiaires pour une transformation de Hadamard du vecteur reçu ;
passage cyclique (206) des co-ensembles d'un sous-code d'un code Reed-Muller du second ordre utilisé pour coder les bits d'information,
exécution (210) de la transformation de Hadamard sur le vecteur reçu comparée à chaque co-ensemble pour obtenir une estimation intermédiaire du mot de code pour chaque cycle ; et
récupération (214), après le passage cyclique par chacun des co-ensembles des bits d'information codés au départ à partir d'une estimation du mot de code finale (212) comprenant la meilleure des estimations intermédiaires de mot de code.

2. Méthode selon la revendication 1, ***dans laquelle*** ledit sous-code comprend un code Reed-Muller du premier ordre.

3. Méthode selon la revendication 1, ***dans laquelle*** l'étape d'exécution de la transformation de Hadamard sur le vecteur reçu comprend de plus les étapes de :

rappel parmi les valeurs intermédiaires pré-calculées à chaque cycle, de celles qui sont nécessaires ; et
exécution de la transformation de Hadamard du vecteur reçu en utilisant les valeurs intermédiaires pré-calculées rappelées pour obtenir l'estimation intermédiaire en ce qui concerne chaque co-ensemble.

4. Méthode selon la revendication 1, dans laquelle la transformation de Hadamard comprend une transformation de Hadamard rapide.

5. Méthode selon la revendication 1, dans laquelle le code Reed-Muller du second ordre comprend une forme abrégée du code Reed-Muller du second ordre.

6. Méthode selon la revendication 1, dans laquelle le code Reed-Muller du second ordre comprend un code Kerdock.

7. Méthode pour le décodage au maximum de vraisemblance d'un vecteur reçu comprenant des bits d'information codés, comprenant les étapes de :

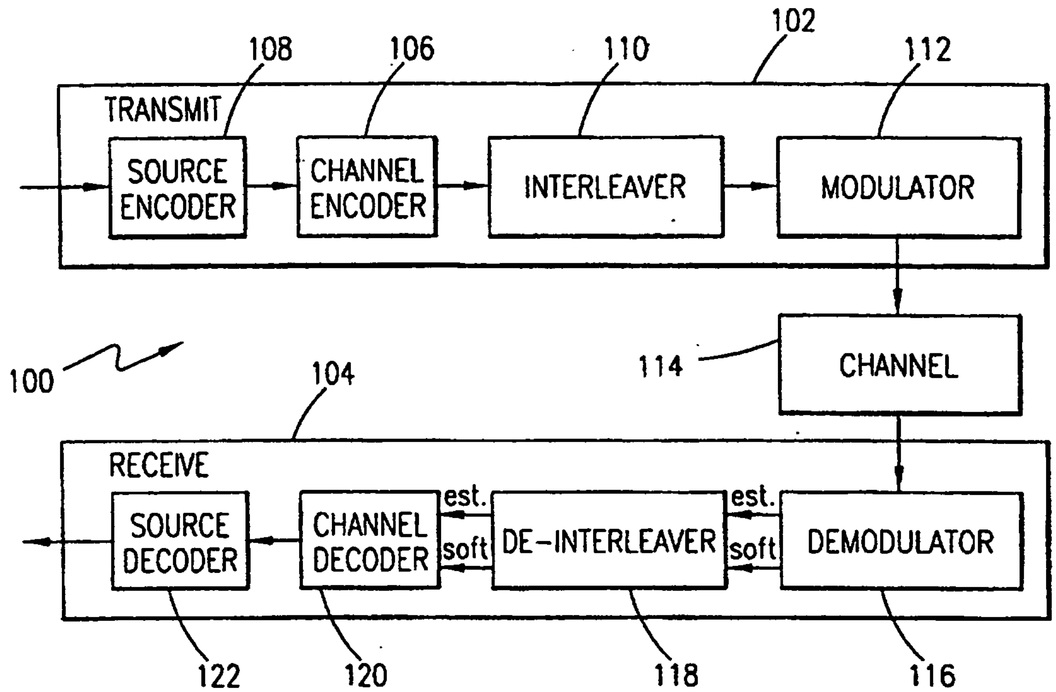
pré-calcul (202) et sauvegarde d'une pluralité de valeurs intermédiaires pour une transformation de Hadamard du vecteur reçu ;
répétition (206) des co-ensembles d'un sous-code d'un code Kerdock utilisé pour coder les bits d'information,

le sous-code comprenant un code Reed-Muller du premier ordre ;
exécution (210) d'une transformation de Hadamard sur le vecteur reçu comparée à chaque co-ensemble pour obtenir une estimation intermédiaire du mot de code pour chaque cycle ; et
récupération (214), suivant la répétition à travers chacun des co-ensembles, des bits d'information codés au départ à partir d'une estimation du mot de code finale (212) comprenant la meilleure des estimations intermédiaires du mot de code.

8. Méthode selon la revendication 7, dans laquelle la transformation de Hadamard comprend une transformation de Hadamard rapide.

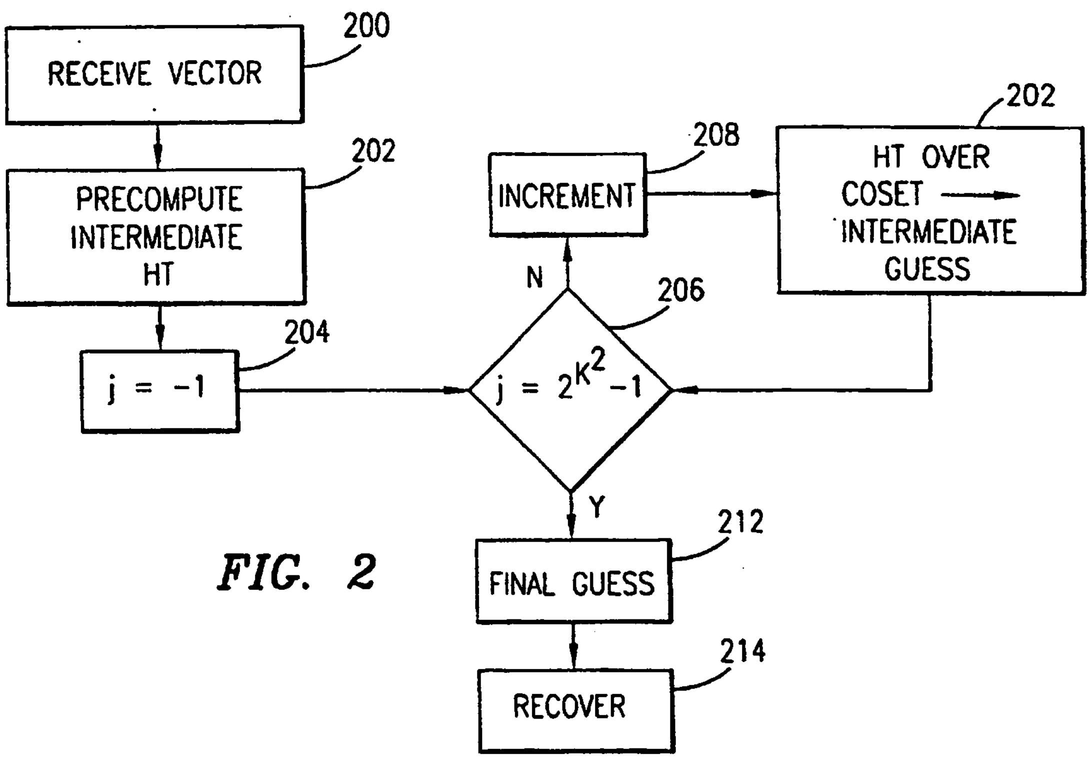
9. Méthode selon la revendication 7, dans laquelle l'étape d'exécution de la transformation de Hadamard sur le vecteur reçu comprend de plus les étapes de :

rappel parmi les valeurs intermédiaires pré-calculées à chaque cycle de celles qui sont nécessaires ; et
exécution de la transformation de Hadamard du vecteur reçu en utilisant les valeurs intermédiaires pré-calculées rappelées pour obtenir l'estimation intermédiaire du mot de code en ce qui concerne chaque co-ensemble.



102
108
106
110
112
TRANSMIT
SOURCE ENCODER
CHANNEL ENCODER
INTERLEAVER
MODULATOR
114
CHANNEL
100
104
RECEIVE
SOURCE DECODER
CHANNEL DECODER
est.
soft
DE-INTERLEAVER
est.
soft
DEMODULATOR
122
120
118
116

FIG. 1



RECEIVE VECTOR
200
PRECOMPUTE INTERMEDIATE HT
202
j = -1
204
INCREMENT
208
HT OVER COSET → INTERMEDIATE GUESS
202
N
206
j = 2K2-1
Y
FINAL GUESS
212
RECOVER
214

FIG. 2